October 2004

Hydro Plant Risk Assessment Guide

Chapter xx: Turbine Condition Assessment

xx.1 GENERAL

The hydraulic turbine is a critical component of a hydroelectric powerplant but it may not be apparent that degradation of the condition of the turbine has occurred. Weld repairs, operation in a "rough zone," and operation on Automatic Generation Control (AGC) all take their toll on the overall condition of the turbine. Efficiency losses are usually gradual and are not noticeable unless efficiency tests are performed. New turbine runners are often not considered unless a considerable uprate is possible or the existing runner is physically failing. Assessing the overall condition of the turbine may show that a replacement runner with a "state of the art" hydraulic design, fabricated from modern materials and refurbishing other components, may provide economic benefits when compared to the current costs of repair and the inefficiency of the existing runner.

xx.2 OBJECTIVES

The objective of performing this assessment is to permit an organization to evaluate the condition of turbines in their different facilities. This information will be utilized to make capital expenditure decisions.

xx.3 SCOPE / APPLICATION

The turbine assessment methodology outlined in this chapter applies to all hydraulic turbines. The entire turbine is considered in this assessment tool, specifically the turbine runner as a major component. At the Facility Manager's discretion, the assessments can be performed on individual turbines or a family of identical or near-identical turbines.

xx.4 CONDITION AND DATA QUALITY INDICATORS, AND TURBINE CONDITION INDEX

Hydro powerplant engineers generally regard the following four condition indicators as providing a sound basis for assessing turbine condition:

- Age
- Runner Physical Condition
- Operational Conditions/Restraints
- Maintenance History

The condition indicators are based on Tier 1 inspections, tests, and measurements conducted by utility staff or contractors over the course of time and as part of routine maintenance activities. Numerical scores are assigned to each turbine condition indicator, which are then weighted and summed to determine the Turbine Condition Index.

An additional stand-alone indicator is used to reflect the quality of the information available for scoring the turbine condition indicators. In some cases, data may be missing, out-of-date, or of questionable integrity. Any of these situations could affect the accuracy of the associated condition indicator scores as well as the validity of the overall Condition Index. Given the potential impact of poor or missing data, a Turbine Data Quality indicator is rated during the Tier 1 assessment as a means of evaluating and recording confidence in the final Turbine Condition Index.

Additional information regarding turbine condition may be necessary to improve the accuracy and reliability of the Turbine Condition Index. Therefore, in addition to the Tier 1 condition indicators, this Guide describes a "toolbox" of Tier 2 inspections, tests, and measurements that may be applied to the Turbine Condition Index, depending on the specific issue or problem being addressed. Tier 2 tests are considered non-routine. However, if Tier 2 data is readily available, it may be used to supplement the Tier 1 assessment. Alternatively, Tier 2 tests may be deliberately performed to address Tier 1 findings. Results of the Tier 2 analysis may either increase or decrease the score of the Turbine Condition Index. The Data Quality Indicator score may also be revised during the Tier 2 assessment to reflect the availability of additional information or test data.

The Turbine Condition Index may be used as the sole justification for replacing or rehabilitating a turbine. The Turbine Condition Index may also be used as input to a computer model that assesses risk and performs economic analysis.

Note: A severely negative result of ANY inspection, test, or measurement may be adequate in itself to require immediate corrective action, regardless of the Turbine Condition Index score.

xx.5 INSPECTIONS, TESTS, AND MEASUREMENTS

Inspections, tests, and measurements ("tests") performed to determine turbine condition are divided into two tiers or levels. Tier 1 evaluations are routinely accomplished as part of normal operation and maintenance and should be, or are readily, discernible by examination of existing data. These indicators may reflect abnormal conditions that can be resolved with standard corrective maintenance solutions. To the extent that Tier 1 tests result in immediate corrective maintenance actions being taken by plant staff, appropriate adjustments to the condition indicator scores should be reflected and the new results used when computing the overall Turbine Condition Index.

Tier 1 test results may indicate the need for further, non-routine evaluation, categorized as Tier 2 tests, that may be applied to assess the specific problem being investigated. The Tier 2 analysis may be used to modify the score of the Turbine Condition Index established using Tier 1 tests and may also confirm or disprove the need for more extensive maintenance, rehabilitation, or replacement.

This guide assumes that Tier 1 and Tier 2 inspections, tests, and measurements are conducted and analyzed by staff suitably trained and experienced in turbine diagnostics. In the case of more basic tests, these may be conducted by qualified staff who are competent in these routine procedures. More complex inspections and measurements may require a turbine diagnostics expert.

This guide also assumes that inspections, tests, and measurements are conducted on a frequency that provides accurate and current information needed by the assessment. In some cases, it may be necessary to conduct tests prior to this assessment to acquire needed data.

Turbine condition assessment may cause concern that justifies more frequent monitoring. Utilities should consider the possibility of taking more frequent measurements or installing on-line monitoring systems that will continuously track critical parameters. This will provide additional data for condition assessment and establish a certain amount of reassurance as turbine alternatives are being explored.

xx.6 SCORING

Condition indicator scoring is somewhat subjective, relying on the experience and opinions of plant staff and turbine experts. Relative terms such as "Results Normal" and "Deterioration" refer to results that are compared to industry-accepted levels; or to baseline or previous (acceptable) levels on this equipment; or to turbines of similar design, construction, or age operating in a similar environment.

xx.7 WEIGHTING FACTORS

Weighting factors may be used in the condition assessment methodology to recognize that some Condition indicators affect the Condition Index to a greater or lesser degree than other indicators. A weighting factor of 1.0 is used to calculate the Turbine Condition Index since the range of scores for each individual condition indicator has been selected to reflect the importance of that condition indicator. This approach was arrived at by consensus among turbine design and maintenance personnel with extensive experience.

xx.8 MITIGATING FACTORS

Every turbine is unique and, therefore, the methodology described in this chapter cannot quantify all factors that affect individual turbine condition. Mitigating factors not included in this Guide may determine the final Turbine Condition Index and the final decision on turbine replacement or rehabilitation. Turbine Condition Indexes will be compared by the respective experts with similar units to flush out abnormalities.

xx.9 DOCUMENTATION

Substantiating documentation is essential to support findings of the assessment, particularly where a Tier 1 condition indicator score is less than 3 (i.e., less than normal) or where a Tier 2 test results in subtractions to the Turbine Condition Index. Test reports, photographs, O&M records, and other documentation should accompany the Turbine Condition Assessment Summary form.

xx.10 CONDITION ASSESSMENT METHODOLOGY

The methodology consists of analyzing each condition indicator individually to arrive at a condition indicator score; then the score is summed with scores from other condition indicators. The sum is the Turbine Condition Index. Apply the Turbine Condition Index to Table 18 – Turbine Condition-Based Alternatives to determine the recommended course of action. Each step is described below.

If routine tests, inspections, and measurements are being performed, then Tier 1 should be performed by maintenance personnel that routinely perform inspections and maintenance activities on the turbine. It is not the intent of Tier 1 to require additional tests, inspections, or measurements. However, when data is missing to properly score the condition indicator, a subjective score may be given by an expert in the area of knowledge. This strategy should be used judiciously to prevent deceptive results. In recognition of the potential impact of poor or missing data, a separate Data Quality Indicator is rated as a means of evaluating and recording confidence in the final Turbine Condition Index.

xx.11 TIER ONE - INSPECTIONS, TESTS, AND MEASUREMENTS

Tier 1 tests include those inspections, tests, and measurements that are routinely accomplished as part of normal operation and maintenance, or are readily discernible by examination of existing data. Tier 1 test results are quantified below as condition indicators that are weighted and summed to arrive at a Turbine Condition Index. Tier 1 tests may indicate abnormal conditions that can be resolved with standard corrective maintenance solutions. Tier 1 test results may also indicate the need for additional investigation, categorized as Tier 2 tests.

xx.12 TURBINE CONDITION INDICATORS

Turbine Condition Indicator 1 – Age

Age is an important factor to consider when identifying candidates for turbine runner replacement or refurbishment. As a turbine ages, it becomes affected by fatigue and becomes susceptible to cracks. The effect of weld repairs over the years can be cumulative, increasing the likelihood of failure. Also, an older turbine has greater potential to be improved by state-of-the-art design and materials. Contours changed by weld repairs will change hydraulics of the runner, reducing its efficiency. In addition, it has been found by a large number of field performance tests that turbine efficiency and capacity declines with age. Most decisions to commence rehabilitation are driven by economics and efficiency, and capacity gains have historically yielded most of the net benefits. Therefore, while age is not relevant when predicting a failure, it is relevant to rehabilitation decision-making. The in-service date will be used to determine turbine age. When looking at a family of turbines that were installed over a period of time at a specific facility, the average age should be used.

The turbine runner age should be determined and applied to Table 1 to arrive at an appropriate Condition Indicator score.

Table 1 – Turbine Age Scoring

Age New / Full Rehabilitation	**Age Partial Rehabilitation**	**Condition Indicator Score**
0 – 25 years	0 – 15 years	3
26 – 35 years	16 – 25 years	2
36 – 45 years	21 – 35 years	1
> 45 years	> 35 years	0

A partial rehabilitation is defined as a new runner with the majority of remaining critical turbine components not restored, or an existing turbine repaired and the majority of remaining critical components (see list below) restored.

Remaining critical components:

- Facing plates and gate end seals
- Discharge ring
- Gate mechanism
- Main shaft bearing
- Wicket gates

The intent of the age criterion for the turbine condition assessment is to indicate performance degradation.

Turbine Condition Indicator 2 – Physical Condition

The surface condition of the waterway is important, especially since it affects the efficiency and capacity of the machine. Areas in the waterway that see the highest velocities will have the largest effects on efficiency. The surface condition of the metal components deteriorates over time due to erosion, corrosion, operating in cavitation zones, and cavitation and cracking damage and repairs. The photographs in Appendix A are to assist in evaluating the surface condition of the runner. The following can be evaluated through inspection of the turbine and its components: the runner, wicket gates, stay vanes, and discharge ring.

Results of the physical inspection are analyzed and applied to Tables 2 and 3 to arrive at condition indicator scores.

Table 2 – Physical Condition - Cracks - Scoring	
Condition *	**Condition Indicator Score**
No cracking	2
Inactive cracks	1
Active cracks	0

* Active cracks are those cracks which when measured are growing over time; inactive cracks are cracks that appear and then when re-measured at a later date have not grown.

Table 3 – Physical Condition - Cavitation and Surface Damage - Scoring	
Condition	**Condition Indicator Score**
Good Surface/Minimal Cavitation Damage	2
Fair Surface/ Moderate Cavitation Damage	1
Poor Surface/Severe Cavitation Damage	0

Turbine Condition Indicator 3 – Operations

Operational limitations play a role in determining the condition of equipment; the greater the limitations, the greater the impact to the power system leading to lost generation and sometimes spilling. Minimal operating restraints include operations to avoid minor rough zones. Moderate operating restraints would include last-on/first-off, hot bearings, large rough zones, high vibration, etc. Severe limitations include situations which make the turbine undesirable to operate such as a blade falling off, or the use of the head gate to stop the unit due to wicket gate leakage. This rating does not include environmental restrictions, e.g., minimum flows, up ramp, or maximum flow limitations.

Operational limitations of the turbine are analyzed and applied to Table 4 to arrive at a Turbine Operational Limitations score.

Table 4 – Operational Limitations Scoring	
Form of Operation	**Condition Indicator Score**
No operating restraints	1.5
Minimal operating restraints	1.0
Moderate operating restraints	0.5
Severe limitations, inoperable	0

Turbine Condition Indicator 4 – Maintenance

The amount of corrective maintenance performed on a piece of equipment is an indication of condition. No corrective maintenance is an indication that the turbine is in good shape. Small amounts of corrective maintenance would be repairs that could be completed during a unit preventative maintenance outage that is scheduled on a periodic basis. Moderate corrective maintenance is maintenance that extends the normal scheduled outage time to perform. Severe corrective maintenance is maintenance that requires scheduled or forced outages to perform. If a Tier 2 rating has been previously made, that rating should be used.

Results of turbine maintenance history are analyzed and applied to Table 5 to arrive at an appropriate Turbine Condition Indicator score.

Table 5 – Corrective Maintenance Scoring

Corrective Maintenance	Condition Indicator Score
No corrective maintenance	1.5
Small amounts of corrective maintenance (e.g., < 3 staff days per unit per year)	1.0
Moderate corrective maintenance that causes extensions of unit preventative maintenance outages	0.5
Severe corrective maintenance or forced outages	0

xx.13 TIER 1 – TURBINE CONDITION INDEX CALCULATIONS

Enter the turbine condition indicator scores from Tables 1 through 5 above into the Turbine Condition Assessment Summary form at the end of this document. Multiply each indicator score by its respective Weighting Factor, and sum the total scores to arrive at the Tier 1 Turbine Condition Index. This index may be adjusted by the Tier 2 turbine inspections, tests, and measurements described later in this document.

The Turbine Condition Index is suitable for use in risk-based economic analysis numerical models. As in all decision-making related to life expectancy of existing equipment, there is a certain amount of uncertainty. Current condition is not a definitive indicator of remaining life; however, it is an important tool to be used to modify traditional life expectancy curves and to arrive at a reasonable, statistically defensible probability of continued life.

xx.14 TIER 1 – TURBINE DATA QUALITY INDICATOR

The Turbine Data Quality Indicator reflects the quality of the inspection, test and measurement results used to evaluate the turbine condition under Tier 1. The more current and complete the inspections, tests, and measurements, the higher the rating for this indicator. The normal testing frequency is defined as the organization's recommended frequency for performing the specific test or inspection.

Qualified personnel should make a subjective determination of scoring that encompasses as many factors as possible under this indicator. Results are analyzed and applied to Table 6 to arrive at an appropriate Turbine Data Quality Indicator Score.

Table 6 – Turbine Data Quality Scoring

Results	Turbine Data Quality Indicator Score
All Tier 1 inspections, tests and measurements were completed within the normal testing frequency.	10
One or more of the Tier 1 inspections, tests and measurements were completed between 6 and 24 months past the normal testing frequency.	7
One or more of the Tier 1 inspections, tests and measurements were completed between 24 and 36 months past the normal testing frequency, or some of the results are not available.	4
One or more of the Tier 1 inspections, tests and measurements were completed more than 36 months past the normal frequency, or no results are available.	0

**********************TIER 2 NOT APPROVED FOR USE**************************

xx.15 TIER 2 – TURBINE INSPECTIONS, TESTS, MEASUREMENTS

Tier 2 inspections, tests, and measurements require specialized personnel to inspect the turbine, interview plant O&M staff and, if necessary, perform a simplified field performance test. The work will require an outage to perform. A Tier 2 assessment is not considered routine. Tier 2 inspections may affect the Turbine Condition Index established using Tier 1. An adjustment to the Data Quality Indicator score may be appropriate if additional information or test results were obtained during the Tier 2 assessment.

Hydraulic turbines, unlike generators and transformers, rarely fail catastrophically and do not really have a physical lifetime. They do have an economic lifetime, however. Because the performance of existing turbines degrades with time, and the value of energy and power and the performance of replacement units increase with time, there comes a point in time when it becomes more economical to rehabilitate them than to continue to operate and maintain them. Families of identical or near-identical turbines at a plant should be evaluated as a group as opposed to individual units.

A team consisting of the Plant O&M Representative and Technical Support Staff should perform Tier 2 assessments.

The tasks that need to be performed for Tier 2 are summarized below:

1) Technical support staff will be responsible to:
   - Visit the plant to perform a physical inspection of a turbine and interview O&M staff.
   - Determine current performance and perform a simplified field test if necessary.
   - Review and, if necessary, adjust the Tier 1 Condition Index based upon the inspection and comparison with the condition of other similar families of units.

2) Plant O&M Representative will be responsible to:
   - Provide necessary assistance and information to Technical Support staff.
   - Assist in the assessment process.

For each Tier 2 test performed, add or subtract the appropriate amount to/from the appropriate Tier 1 Condition Indicator and recalculate the Turbine Condition Index.

Test T2.1: Efficiency Test

The efficiency of the turbine is probably the most important factor in determining if a turbine runner should be replaced. The efficiency test may show that the condition of the turbine has degraded to a point that its efficiency has been reduced significantly. Even if efficiency hasn't degraded, newer turbine designs are usually more efficient than those 30 years or older. In addition, many turbines were designed for best efficiency head in the mid-range of the reservoir elevation swing, but operational philosophy has changed. An efficiency increase and decreased cavitation can be gained from installing a replacement runner that is designed around a head range established from historical operations rather than original design data.

Turbine efficiency test results are analyzed and applied to Table 7 to arrive at a Turbine Condition Index score adjustment.

Table 7 – Efficiency Test Scoring

Measured Efficiency Test Results	Adjustment to Condition Index Score
Measured efficiency is greater than 93 percent or < 2 percent less than original efficiency	Add 1.0
Measured efficiency is between 91 and 93 percent or between 2 to 3 percent less than original efficiency	No Change
Measured efficiency is less than 91 percent or > 3 percent less than original efficiency	Subtract 1.0

Test T2.2: Capacity Test

The capacity of the turbine is another important factor in determining if a turbine runner should be replaced. As efficiency degrades over time, so does the maximum capacity of the machine. Tests may show that the condition of the turbine has degraded to a point that its capacity has

been reduced significantly, sometimes more than 4 percent. Installing a new runner will restore maximum capacity to original output level. In some cases, a new runner may provide an opportunity to increase the capacity above the original design.
Capacity test results are analyzed and applied to Table 8 to arrive at a Turbine Condition Index score adjustment.

Table 8 – Capacity Test Scoring

Measured Capacity Range	Adjustment to Condition Index Score
Lost < 2 percent from original capacity	Add 0.5
Lost between 2 to 4 percent from original capacity	No Change
Lost > 4 percent from original capacity	Subtract 0.5

Test T2.3: Off-Design Conditions Test

Consideration of current conditions must be given. If there is a significant change in the flow rate or head from the original design condition, this can greatly impact the machine performance and lead to recurring maintenance issues.

Test results from design conditions are analyzed and applied to Table 9 to arrive at a Turbine Condition Index score adjustment.

Table 9 – Off-Design Conditions Test Scoring

Changes in Design Conditions	Adjustment to Condition Index Score
No significant changes from original design	No Change
Significant changes in flow rate or head since original design	Subtract 0.5

Test T2.4: Paint Film Quality Test

A visual inspection should be made of the ferrous portions of the spiral case and extension, stay vanes, wicket gates, runner, discharge ring, head cover and draft tube. The film quality will be scored and compared to those of other units.

Paint Film Quality test results are analyzed and applied to Table 10 to arrive at a Turbine Condition Index score adjustment.

Table 10 – Paint Film Quality of Ferrous-Wetted Surfaces Test Score	
Paint Film Quality Test	**Adjustment to Condition Index Score**
Paint film is mostly intact (90 percent or more of the surface is intact)	Add 0.5
The paint film is mostly absent but the steel surfaces have not yet suffered serious corrosion or erosion damage	No Change
Ferrous surfaces exhibiting extensive erosion or corrosion attack are observed (or need to be periodically repaired) in critical areas (stay vanes, wicket gates, around (or in) man-door or in spiral case or penstock)	Subtract 0.5

Test T2.5: Surface Roughness of Runner and Discharge Ring Test

During the physical inspection, surface quality comparison gages or measurement tools will be used to determine the surface roughness. Roughness can be caused from cavitation attack, erosion, corrosion or any combination of the three.

Surface quality comparison test results are analyzed and applied to Table 11 to arrive at a Turbine Condition Index score adjustment.

Table 11 – Surface Roughness of Runner and Discharge Ring Test Scoring	
Surface Quality	**Adjustment to Condition Index Score**
Good	Add 0.5
Moderate	No Change
Severe	Subtract 0.5

Test T2.6: Cracking of Runner and Discharge Ring Test

O&M personnel will be interviewed to determine and document the cracking repair history. If the cracking problem has been permanently solved (i.e., no observed cracks have occurred in the last 10 years), it will be scored as “minimal.” If cracking occurs, but in non-critical areas, it will be scored “moderate.” See the sketches in Appendix B. Critical areas are those labeled I and II. All other areas are considered non-critical.

The cracking repair test results are analyzed and applied to Table 12 to arrive at a Turbine Condition Index score adjustment.

Table 12 – Cracking of Runner and Discharge Ring Test Scoring	
Cracking During Last 10 Years	**Adjustment to Condition Index Score**
Minimal, i.e., none, or not active in non-critical areas and < 1” long	Add 1.0
Moderate, i.e., active but in non-critical areas and between 1” and 2” long	No Change
Severe, i.e., active in critical areas or > 2” long	Subtract 1.0

Test T2.7: Cavitation of Runner and Discharge Ring Test

Both the average depth of the worst pitting and area of damage should be considered. Photographic evidence could be utilized in the event a physical inspection is not possible.

The following areas will be inspected: Suction side of the vanes/blades near the band, pressure side of the blade/vane near the leading edge, discharge ring/18 inches below the runner, and runner hub adjacent to blades.

The cavitation damage test results will be analyzed and applied to Table 13 to arrive at a Turbine Condition Index score adjustment.

Table 13 – Cavitation Damage of Runner and Discharge Ring Test Scoring	
Cavitation Damage	**Adjustment to Condition Index Score**
Minimal: Stainless – frosting only Carbon – frosting only	Add 0.5
Moderate: Depth Area Stainless < 1/8” < 5% Carbon < 3/8” < 5%	No Change
Severe: Depth Area Stainless > 1/8“ > 5% Carbon > 3/8” > 5%	Subtract 0.5

Test T2.8: Condition of Remaining Parts and Systems Test

In addition to the turbine runner, there are many other parts and systems which need to function to enable the turbine to operate satisfactorily. Each one by itself would not necessarily change the condition assessment score of the unit. However taken together, an overall assessment can be made. The following is a list of other components and considerations:

- Gate mechanism (servo motors, shift ring, wicket gate locking mechanisms, bushings)
- Guide bearing
- Seals
- Oil-head if Kaplan

- Blade adjusting mechanism if Kaplan
- Alignment/verticality
- Concrete growth
- Run-out
- Vibration
- Noise
- Greasing system
- Oil circulating pumps
- Headcover drains or pumps
- Vacuum breakers

Test results from the condition of all remaining parts and systems are analyzed and applied to Table 14 to arrive at a Turbine Condition Index score adjustment.

Table 14 – Condition of Remaining Parts and Systems Test Scoring

Equipment Condition	Adjustment to Condition Index Score
All sub-systems are normal and there are no major issues in any of the listed areas. In general, very little maintenance is required.	Add 0.7
Some sub-systems require frequent maintenance or do not operate well. Frequent minor maintenance is needed to keep the unit running well.	No Change
The unit runs but takes significant or frequent maintenance. Some more important components are damaged or broken.	Subtract 0.7

Test T2.9: Environmental Improvement Test

The primary environmental issues relative to turbines are losing oil or grease into the waterway, poor survival of fish passing through them, and low-dissolved oxygen (DO) content of released water during portions of the year. Facilities without environmental issues score "No Change."

Table 15 – Environmental Improvement Test Scoring Environmental Conditions	Adjustment to Condition Index Score
There are no perceived environmental issues and rehabilitation of the turbine would have minimal positive effect on the environment. Little or no oil or grease is released into the environment and no DO improvements can be gained by a turbine replacement.	Add 0.5
There is some history of negative impacts (occasional minor oil releases, some mortality of fish which transit the turbine, and most years, the desired dissolved oxygen content of released water is met or exceeded during all months).	No Change
There are known negative impacts which regularly occur which can be mitigated by a turbine rehabilitation. Significant amounts of oil or grease are occasionally released into the environment. Or, DO improvements or fish passage survival improvements can be gained by a turbine replacement.	Subtract 0.5

Environmental Improvement test results are analyzed and applied to Table 15 to arrive at a Turbine Condition Index score adjustment.

Test T2.10: Operating Conditions Test

Operating conditions are a good indicator of wear on a machine. Conditions such as the loading of a machine; i.e., base loaded or peaking, AGC, condensing, and the number of start/stops may lead to accelerated damage to units.

Test results from the operating conditions are analyzed and applied to Table 16 to arrive at a Turbine Condition Index score adjustment.

Table 16 – Operating Conditions Test Scoring Form of Operation (Annually)	Adjustment to Condition Index Score
Base Loaded	Add 0.5
Peaking operation, AGC or < 100 start/stops or condensing cycles	No Change
>100 start/stops or condensing cycles	Subtract 0.5

Test T2.11: Maintenance Test

The O&M staff should work with Engineering support staff to evaluate the past 5 to 10 years' maintenance records to determine the level of maintenance required to maintain the unit. Due to the individual nature of each facility and how it is operated and maintained, it is intended that this evaluation will be different for each facility. The intent is to re-look at the initial Tier 1 evaluation and make adjustments accordingly. The facility should have maintenance records available prior to the evaluation starting to ensure the assessment goes smoothly.

The evaluation reports on maintenance records are analyzed and applied to Table 17 to arrive at a Turbine Condition Index score adjustment.

Table 17 – Maintenance Test Scoring

Maintenance Performed	Adjustment to Condition Index Score
Normal maintenance	Add 0.5
Additional maintenance during normal outages	No Change
Additional outages or extended outages needed to perform maintenance task or maintenance work deferred due to lack of time	Subtract 0.5

Test T2.12: Other Specialized Diagnostic Tests

Additional tests may be applied to evaluate specific turbine problems. Some of these diagnostic tests may be considered to be of an investigative research nature. When conclusive results from other diagnostic tests are available, they may be used to make an appropriate adjustment to the Turbine Condition Index.

xx.16 TIER 2 – TURBINE CONDITION INDEX CALCULATIONS

Enter the Tier 2 adjustments from the tables above into the Turbine Condition Assessment Summary form at the end of this guide. Subtract the sum of these adjustments from the Tier 1 Turbine Condition Index to arrive at the Net Turbine Condition Index. Attach supporting documentation. An adjustment to the Data Quality Indicator score may be appropriate if additional information or test results were obtained during the Tier 2 assessment.

xx.17 TURBINE CONDITION-BASED ALTERNATIVES

The Turbine Condition Index – either modified by Tier 2 tests or not – may be sufficient for decision-making regarding turbine alternatives. The Index is also suitable for use in the risk-and-economic analysis model described elsewhere in this Guide. To determine the risk of any course of action or the long-term economic impacts, the computer model must be used. Where it is desired to consider alternatives based solely on turbine condition, the Turbine Condition Index may be directly applied to Table 18 – Turbine Condition-Based Alternatives below.

Table 18 – Turbine Condition-Based Alternatives	
Turbine Condition Index	**Suggested Course of Action**
≥ 7.0 and ≤ 10.0 (Good)	Continue O&M without restriction. Repeat or update Tier 1 assessment during next scheduled maintenance outage.
≥ 3.0 and ≤7.0 (Fair)	Continue O&M without restriction. Schedule a Tier 2 assessment in 4 years or less.
≥ 0 and ≤ 3.0 (Poor)	Schedule a Tier 2 assessment in 1 year.

TURBINE
TIER 1 CONDITION ASSESSMENT SUMMARY

Date: ________________________ Turbine Identifier: ______________________

Location: ______________________ Manufacturer: ________ Yr. Mfd. _______

Tier 1 Turbine Condition Summary *(For instructions on indicator scoring, please refer to condition assessment guide)*				
No.	**Condition Indicator**	**Score X**	**Weighting Factor =**	**Total**
1	**Age** *(Score must be 0, 1, 2, or 3)*		1.000	
2	**Physical Condition** *(Score must be 0, 1,or, 2)*		2.000	
3	**Operations** *(Score must be 0, 0.5, 1, or 1.5)*		1.000	
4	**Maintenance** *(Score must be 0, 0.5, 1, or 1.5)*		1.000	
	Tier 1 Turbine Condition Index (Sum of individual Total Scores) *(Condition Index should be between 0 and 10)*			

Turbine Data Quality Indicator *(Value must be 0, 4, 7, or 10)*	

Evaluator: ______________________ Technical Review: ________________________

Management Review: _____________ Copies to:______________________________

(Attach supporting documentation.)

Turbine Condition Index-Based Alternatives	
Condition Index	**Suggested Course of Action**
≥ 7.0 and ≤ 10 (Good)	Continue O&M without restriction. Repeat or update Tier 1 condition assessment during next scheduled maintenance outage.
≥ 3.0 and < 7 (Fair)	Continue O&M without restriction. Schedule a Tier 2 assessment in 4 years or less.
≥ 0 and < 3.0 (Poor)	Schedule a Tier 2 assessment in 1 year.

Tier 1 Indicator	Last Prior Tier 1 Score	Tier 2 Indicators	Adjustment (plus or minus)	Total Adjustment	Score	Total Score
Age		Efficiency				
		Capacity			(Can’t be <0)	
		Off-Design			(Can’t be >3)	
Physical Condition		Paint				
		Roughness				
		Cracking				
		Cavitation				
		Condition of Remaining Parts			(Can’t be <0) (Can’t be > 4)	
Operations		Environmental				
		Operating Conditions			(Can’t be <0) (Can’t be > 1.5)	
Maintenance		Maintenance			(Can’t be <0) (Can’t be > 1.5)	
Other		Specialized Diagnostic Tests				
Total						

Appendix A

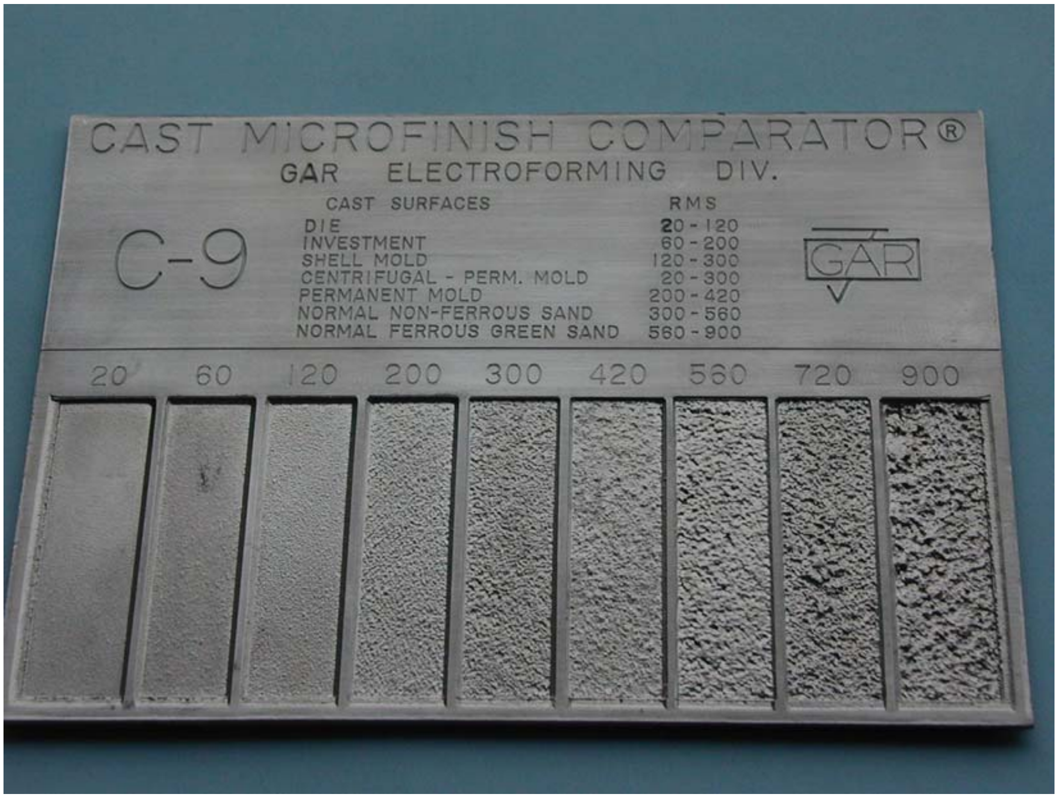

Figure A-1: Surface roughness standard - good (left) to poor (right). This is a casting standard and the left 3 should never be expected to indicate a good runner surface.

Figure A-2: Stainless steel – fair condition.

Figure A-3: Stainless steel – poor condition.

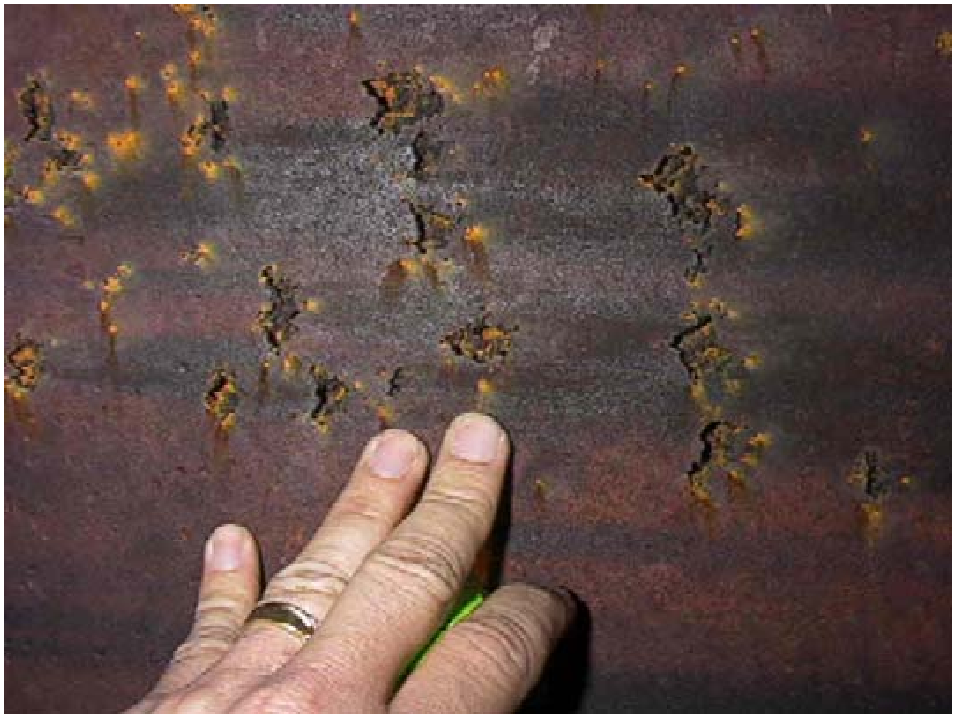

Figure A-4: Carbon steel – fair condition (pitting).

Figure A-5: Carbon Steel - poor condition

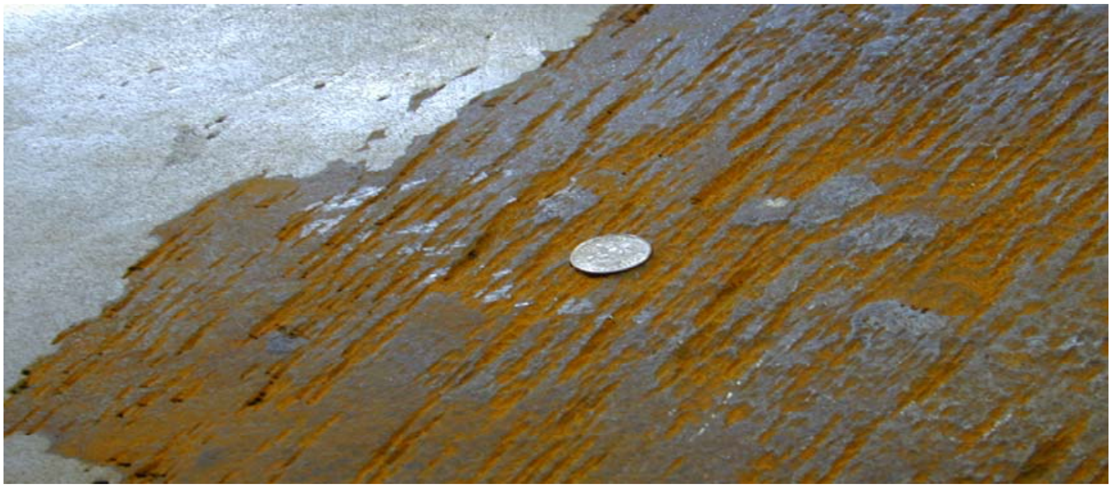

Figure A-6: Carbon steel – poor condition.

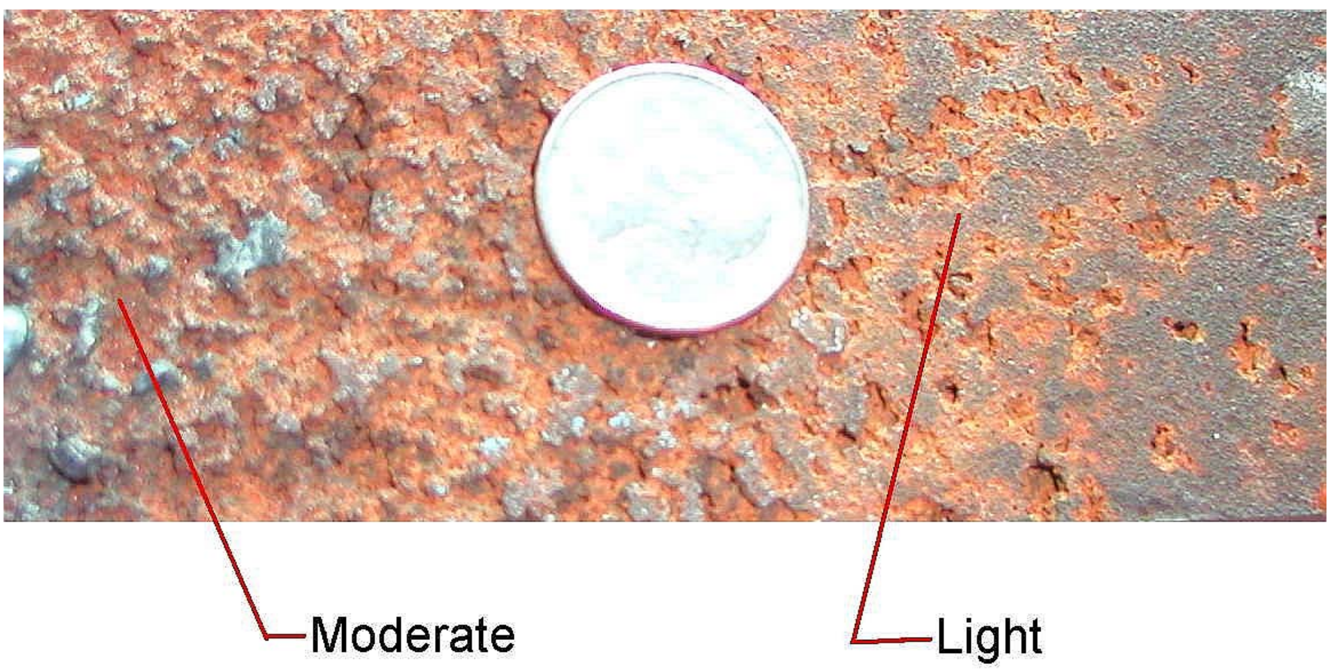

Figure A-7: Carbon steel.

Figure A-8: Carbon steel – poor condition.

Appendix B

(As Referenced for Test T2.S6)

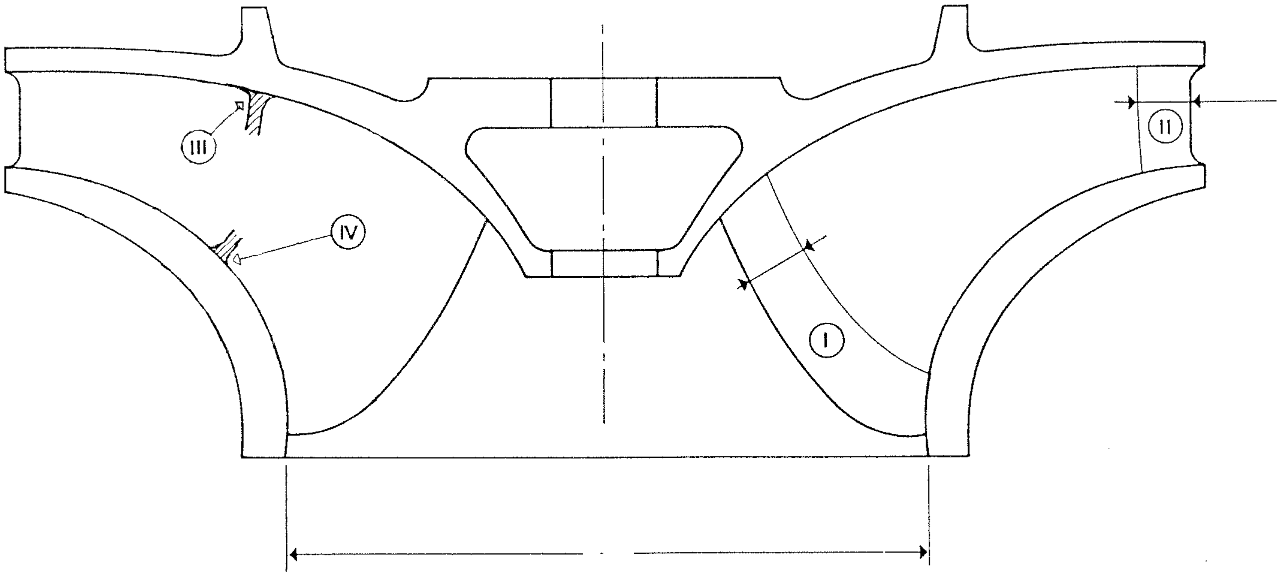

Figure B-1: Francis Runner critical areas

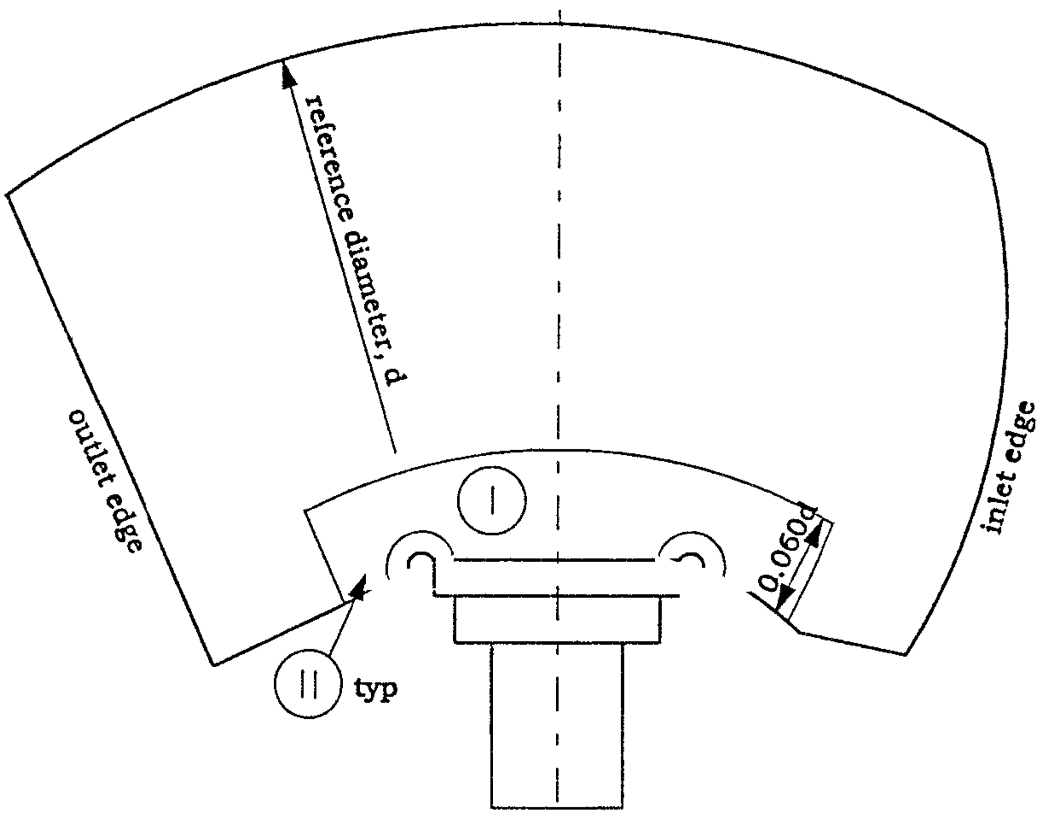

Figure B-2: Kaplan blade critical area

B-3 Checklists

These checklists are to be used as a guide while performing the physical inspection performed during the Tier 2 assessment.

Kaplan Turbine-Generator Mechanical Inspection Check List

1. **General - Turbine**

    Manufacturer & Serial #'s
    Model test exist
    Original contract exist
    Original O&M manual exist
    Rated power & head
    Synchronous speed (RPM)
    Overhaul frequency
    Date of commissioning
    Index test(s) performed/test reports exist
    Latest REMR Condition Index No. ____ & Date ________
    Vibration monitors installed
    Turbine flowmeter equipment installed
    Known asbestos or other hazardous material problems
    Weight of rotating parts known
    Weight of heaviest lift known
    Maximum hydraulic thrust known
    River water quality (corrosiveness/PH/etc)
    Does trash rake exist and is it effective

    Operation

    Typical plant operation (peaking/run-of-river/mixed)
    Operating restrictions (FB, TW, MW)
    Minimum discharge requirement
    Noise & vibration levels/rough spots
    Format of recorded hourly & daily data (what & how)
    Dissolved oxygen problems
    Fish passage problems
    Trash build up problems
    Frequency of trash raking

2. **Paint Condition** **wetted parts** **non-wetted parts**

    Type
    Contain lead or PCB's
    Age
    Condition

3. **Oil Leaks**

    Blade servo

Past piston rings
Past rod rings
Gate servo
Piston rings
Rod seals
Piping
Hub
Plugs (on top)
Blade packing
Drain valve
Oil head & piping
Static column packing
Outer pipe packing
Past bushing between pressure chambers
At connection to hub/blade servo
Guide bearing housing(s)

4. **Gate Mechanism**
Servomotor
Anchor bolts tight
Piston rod bent
Rod/rod end connection tight
Rod chrome plated/scored
Amount of "squeeze" (inches)
Stop nut
Automatic gate lock
Manual gate lock
Gate ring bearings
Shear pins
Link pins
Links
Shear levers
Gate levers
Stops
Gate damping mechanism
Gates
Clearances (nose/tail, top & bottom)
Calibration record(s) of opening vs servo stroke
Any history of losing total top/bottom clearance
Seal type (tops & bottoms) & condition (if any)
Greasing to bushings ok
Water leakage past stem packing
Type of stem seal material
Any SS on tops or bottoms

5. Stationary Parts

Outer, intermediate, & inner head covers

- Cracking
- Broken bolts
- Radial bolts
- Dowels tight
- Bolt tightness checked during overhauls

Head cover pumps, motors, and controls

Vacuum breaker valves & check valves

Oil slinger sumps, pumps & controls

6. Guide Bearing(s) and Packing Box

Bearing

- Heat exchanger location
- Bearing temps normal
- Original shoes/shell
- Self lube or pumped
- Type & grade of oil used
- Cooler condition
- Bearing cooling water flow required in gpm
- Runout & skate of shaft at guide bearing

Packing Box

- Repair history
- Type & grade of packing used
- Flow rate of cooling/lube water in gpm
- Frequency of packing adjustment

7. Embedded Parts

Stay ring & vanes

- Crack & repair history
- W-K taps intact & operational
- Are there net head taps

Spiral case

- Concrete condition
- Outer W-K tap ok
- Net head tap(s) installed
- Mandoor/access hatch condition
- Elevator/personnel hoist

Bottom Ring

- Wear/galling between W-G & facing plates
- SS or carbon steel facing plates

Discharge Ring

- Est. weight of SS overlay weld normally installed during overhauls
- Roundness checked
- SS overlay band welded & machined in place

Draft Tube

Mandoor & frame
Pier nosings
Access platform exist
Effort to install platform (mh & crew size)
Pit liner drainage

6. **Rotating Parts**

Main shaft (connected to hub)
Painted
Coupling bolts
Packing sleeve
Condition below sleeve
Bearing journal
Hub water drain tap
Shoulder for support of weight when disconnected from generator shaft
Oil head concentric pipes
Intermediate shaft (if any)
Painted
Coupling bolts
Blade servo shaft (if any)
Painted
Coupling bolts

Runner Assembly

General
Ever been disassembled since original installation
Blades
Modifications
Cavitation
Cracking
Breakage
Size of blade/palm intersection radii
Area of SS overlay
Amount of SS overlay weld applied at overhaul (lbs)
Frequency of Cavitation repairs
Clearance between discharge ring & blade tips
Are trailing edges tapered
OEM blade angle marks still exist
Hub
Cavitation
Cracking
Trunnion bushing wear
Oil leakage past blade seals
Frequency of adjustment of blade packing
Lubricant grade and type
Hub oil isolated from governor oil
Blade servo in hub – If yes, is it above or below Blade CL

Water inflow amount per year – gal

Blade adjustment mechanism

- Links & link pins
- Cross head
- Crosshead keys and keyways
- Eye ends
- Rocker arms
- Blade trunnion keys
- Bell crank & pins (if applicable)

Operating Rod (if servo in shaft)

Blade servo

- Cylinder
- Piston
- Piston rings
- Piston rod rings
- Piston cap

7. Turbine Tools and Erection Devices

Runner erection pedestal
Slugging wrenches or sockets
Availability of hydraulic wrench
Shaft lifting device
Hub lifting device
Head cover lifting links

8. Spare Turbine Parts on Hand

Turbine guide bearing shell/shoes
Main shaft sleeve
Wicket gate(s)
Runner blade(s)
Other

9. Generator Tools and Erection Devices

Shaft support pedestal
Slugging wrenches or sockets
Shaft lifting device
Rotor lifting device

10. Mechanical Components of Generator

General

- Drawings
- OEM O&M manual
- Manufacturer & Serial #'s
- Direction of rotation looking down

Shaft

- Condition
- Runout & skate of shaft at guide bearings

upper
lower

Guide Bearings
- Type (shell or shoe)
- Normal operating temperature
- Cooler condition
- Cooling water flow rate (gpm)
- Lube oil pumped or self lubed
- Housing condition (leaks, rust inside)

Thrust Bearing
- Manufacturer (GE, Westinghouse, Kingsbury, other)
- Type (springs, pivoted pad, equalizing, etc)
- High pressure oil pump system
- Normal operating temperature
- Cooler condition
- Cooling water flow rate (gpm)

Structural
- Rotor spider
- Bolts
- Stator frame
- Dovetails (on back iron)
- Shaft keys stay tight
- Stator back iron condition
- Upper & lower bearing bracket

Brakes & Jacks
- Piston condition
- Brake pad material (asbestos or not)
- Brake ring condition
- Operational problems

Air coolers
- Leaking tubes

CO^2 System

11. Spare Generator Mechanical Parts on Hand

Guide bearing shoes or shells (upper/lower)
Thrust runner
Thrust bearing shoes
Oil coolers
Air coolers
Other

12. Governor

Manufacturer & Serial Nos.
Model No.
Pressure Tank
- Pressure rating (psi)
- ASME Code stamped

Air safety installed
Interior paint condition
Float valve
Sump Condition (interior)
Pumps
Type (screw or gear)
Number & GPM
Motor speed & HP
Availability of spare parts
Cycle time
Unloader valve operation ok
Distributing valve spool & sleeve condition
Is a digital retrofit desired
Blade control cam type (2-D, 3-D mechanical, or 3-D electronic)

13.0 Lube Oil

ISO Grade
Supplier (Mobil, Texaco, etc.)
Age
Quantities (gal.)
Governor
Turbine hub
Turbine guide bearing
Thrust bearing
Generator guide bearing(s)
Condition
RBOT No.
Total Acid No. (TAN)
Viscosity

Francis Turbine - Field Visit & Inspection Check List

2. General

Turbine manufacturer & serial #
Shop drawings
Original model test exist
Original contract exist
Original turbine O&M manual exist
Rated power & head
Synchronous speed (RPM)
Overhaul frequency
Date of commissioning
Gibson & Index test(s) performed/test reports exist
Any other field tests performed (full gate, baffle, runaway, etc.)
Latest REMR Condition Index No. ____ & Date ________
Vibration monitors installed (locations & types)
Turbine flowmeter equipment installed

Known asbestos or other hazardous material problems
Weight of rotating parts
Weight of heaviest lift
Maximum hydraulic thrust
River water quality (corrosiveness, PH, etc.)
Does trash rake exist and is it effective

Operation & Maintenance

Typical plant operation (peaking/run-of-river/mixed)
Operating restrictions (FB, TW, MW)
Units operate similarly
Is maintenance similar on units
Minimum discharge requirement
Noise & vibration levels/rough spots
Hourly data recorded (what & how)
Dissolved oxygen problems
Fish passage issues/problems
Trash build up problems
Frequency of trash raking

2.	**Paint Condition**	**wetted parts**	**non-wetted parts**
	Type		
	Contain lead or PCB's		
	Age		
	Condition		

3. Oil Leaks

Gate servos
- Piston rings
- Rod seals
- Piping

Guide bearing housing(s)

4. **Gate Mechanism**

Servomotor
- Anchor bolts tight
- Piston rod bent
- Rod/rod end connection tight
- Rod chrome plated/scored
- Amount of "squeeze" (inches)
- Stop nut

Automatic gate lock
Manual gate lock
Gate ring bearings
Shear pins

Link pins
Links
Shear levers
Gate levers
Stops
Gate damping mechanism
Gates
- Clearances (nose/tail, top & bottom)
- Calibration record(s)
- History of losing total clearance
- Upper & lower seal type & condition (if any)
- Greasing to bushings ok
- Do stems have SS sleeves or SS weld overlay
- Water leakage past stem packing
- Type of stem seal material

5. **Stationary Parts**

Head cover
- Cracking
- Broken bolts
- Dowels tight
- Bolt tightness checked during overhauls
- Drainage ok

Vacuum breaker valves & check valves

7. **Guide Bearing(s) and Packing Box**

Bearing
- Heat exchanger type & location
- Bearing temps normal
- Original shoes/shell
- Self lube or pumped (gpm if pumped)
- Type & grade of oil used
- Bearing cooling water flow required in gpm
- Shaft runout & skate

Packing Box
- Repair history
- Type & grade of packing used
- Flow rate of cooling/lube water in gpm
- Frequency of packing adjustment

8. **Embedded Parts**

Net head, Gibson & W-K taps & piping condition
Stay ring & vanes
- Vane surface quality
- Crack & repair history

Spiral case
- Condition

Riveted or welded
Mandoor/access hatch condition
Bottom Ring
Wear/galling
SS or carbon steel
Discharge Ring
Est. weight of SS overlay weld normally installed during overhauls
Draft Tube
Mandoor & frame
Pier nosings
Access platform exist
Effort to install platform (mh)
Head cover drainage

9. **Rotating Parts**
Main shaft
Painted
Coupling bolts
Packing sleeve
Condition below sleeve
Bearing journal
Shoulder for support of weight when disconnected from generator shaft
Intermediate shaft (if applicable)
Painted
Coupling bolts

10. **Runner**
General
No. of vanes
Cavitation on crown or band
Ever been removed (out of hole) since original installation
Baffles installed
Vanes
Surface quality
Modifications
Cavitation
Cracking
Breakage
Area of SS overlay
Amount of SS overlay weld applied at overhaul (lbs)
Clearance between wear rings & seals (upper & lower)
Are trailing edges tapered

11. **Tools and Erection Devices**
Slugging wrenches or sockets
Shaft lifting device
Runner lifting device
Availability of hydraulic wrench

12. **Spare Parts on Hand**

- Guide bearing shell/shoes
- Main shaft sleeve
- Wear rings (upper & lower)
- Wicket gate(s)
- Other

13. **Air Depression System (if applicable)**

- General
  - Frequency of use
  - Work ok
  - Time required for blow down
  - Time needed to recharge receivers
- Air receivers
  - Number
  - Volume
  - Pressure rating
  - Code stamped
  - Air safety valve size
  - Condition (external & internal)
  - Who does inspections
  - Date of last inspection
  - Automatic condensate trap
- Compressors
  - Number
  - Type
  - Condition
  - Capacity (SCFM)
  - Pressure rating
  - Motor voltage, HP & RPM
  - Intercooler & aftercooler type
  - Mfgr

14. **Butterfly Valve (if applicable)**

- General
  - Drawings
  - Manufacturer
  - Original contract
  - OEM O & M manual exist
  - Maximum design pressure rating
  - Typical operation (normally closes upon unit shutdown)
  - Type of seals (rubber/metal)
  - Operational problems
  - Leakage rate when closed
  - Spare parts
  - Tools & erection devices

- Body
  - Condition (structural, corrosion, paint, etc.)
  - Method of adjusting seal or seat
  - Condition of seat or seal
  - Bypass valves & actuators
  - Paint condition
- Disk
  - General condition
  - Type (lenticular/truss)
  - Sealing surface condition
- Actuator
  - Counterweight
  - Manual & automatic locks
  - Hydraulic Cylinder Condition
  - Hydraulic power unit
    - Operational problems
    - Operating pressure
    - Pump capacity & type
    - Accumulator capacity, type & condition
    - Motor voltage, rpm, hp

15. **Mechanical Components of Generator**

- General
  - Drawings
  - OEM O&M manual
  - Manufacturer & Serial #
  - Direction of rotation looking down
- Shaft
  - Runout & skate at upper & lower guide bearings
  - Condition
- Guide Bearings
  - Type (shell or shoe)
  - Normal operating temperature
  - Cooling water flow rate (gpm)
  - Lube oil pumped or self lubed
  - Housing condition (leaks, rust inside)
- Thrust Bearing
  - Manufacturer (GE, Westinghouse, Kingsbury, other)
  - Type (springs, pivoted pad, equalizing, etc)
  - High pressure oil pump system
  - Normal operating temperature
  - Cooling water flow rate (gpm)
- Structural
  - Rotor spider
  - Bolts
  - Stator frame
  - Dovetails (on back iron)

- Shaft keys stay tight
- Stator back iron condition
- Upper & lower bearing bracket

Brakes & Jacks
- Piston condition
- Brake pad material (asbestos or not)
- Brake ring condition
- Operational problems

Air coolers
- Leaking tubes

CO^2 System

Lifting Devices
- Rotor
- Shaft
- Rotor support pedestal

Spare parts
- Guide bearing shoes or shells (upper/lower)
- Thrust runner & pads
- Air coolers
- Other